Contractor's Report to the Board

The Feasibility, Constructability, and Efficacy of Tire-Derived Aggregate as a Component in Slurry Cutoff Walls

Produced under contract by:

CALIFORNIA STATE UNIVERSITY, CHICO

CSU, Chico Research Foundation

June 2006

California Environmental Protection Agency
Integrated Waste Management Board

For additional copies of this publication, contact:

Integrated Waste Management Board
Public Affairs Office, Publications Clearinghouse (MS–6)
1001 I Street
P.O. Box 4025
Sacramento, CA 95812-4025
www.ciwmb.ca.gov/Publications/
1-800-CA-WASTE (California only) or (916) 341-6306

Publication #621-06-009
Printed on recycled paper containing a minimum of 30 percent postconsumer fiber.

Prepared as part of contract no. IWM–C2069X (total contract amount: $30,000, includes other services).

Table of Contents

Executive Summary 3
Overview 3
Laboratory Work 4
Large Scale Field Test 4
Monitoring of Results 5
Laboratory Phase 7
Preliminary Investigations 7
Mix Design and Parameters 7
Testing Procedures 9
Medium Scale Testing 9
Full Scale Demonstration Project 11
Site Selection 11
Permitting for the Project 12
Contractor Selection 12
Construction Process 12
QA/QC 13
Lessons Learned 13
Monitoring 14
Post Project Preliminary Monitoring 14
Methods of Periodic Monitoring 14
Results of Periodic Monitoring 15
Secondary Monitoring Method 16
Results of Secondary Monitoring Method 16
Summary 18
Abbreviations and Acronyms 19

Executive Summary

Overview

This project was originally developed conceptually as a potential reuse for large quantities of waste tires which may be recycled by cutting them into tire shreds. Tire shreds have unique physical properties which may be used in various civil engineering applications. In 1998, a research grant was awarded to the CSU, Chico Research Foundation to evaluate the feasibility of incorporating tires shreds into a levee slurry cutoff wall. Professor Richard G. Holman authored the study.

A slurry cutoff wall is a form of seepage barrier intended to stop the migration of water through an impervious barrier. One of the methods used to construct a slurry cutoff wall is to excavate a trench and then backfill with a mixture of soil, cement, and bentonite clay (SCB). In waterside applications, a cutoff wall is typically constructed either at the toe of the levee or along the crown (top) of the levee. The process is typically:

1. A trench is excavated.
2. The trench is filled with hydrated bentonite clay slurry to prevent the trench from caving in.
3. The soil that was excavated is mixed with bentonite and cement and placed back into the trench.
4. Samples are periodically taken to measure the permeability (ability of water to flow through the backfill material).

In the 1990's the United States Army Corps of Engineers (USACOE) constructed more than 25 river miles of slurry cutoff walls per year on various rivers in Northern California. Additionally, cutoff wall contracts were let by various government agencies including the California Department of Water Resources (DWR), and the United States Bureau of Reclamation (USBOR). The hypothesis for this project was that a large quantity of recycled tires could be incorporated into the backfill, alleviating the various piles of waste tires stockpiled in the State of California and providing an effective barrier to water migration.

The Recycled Tire Slurry Cutoff Wall Demonstration Project was funded by the California Integrated Waste Management Board as a potential source for the reuse of waste tires. The project had four distinct stages:

1. Laboratory Testing
2. Medium Scale Testing
3. Large Scale Field Testing - Implementation
4. Monitoring of Results

Laboratory Work

In 1998-1999, preliminary laboratory work was performed to determine if in fact, there was a method in which the soil, cement, bentonite, and tire shreds could be mixed resulting in a product that behaved similar to backfill materials being used in traditional SCB cutoff walls. The target used for measurement of performance was the USACOE specifications with three major criteria including:

1. Slump – 100–150 mm (4-6 inches)
2. Permeability – Less than 5 x 10^{-7} cm/sec
3. Compressive strength (f_c) – Less than 100 psi

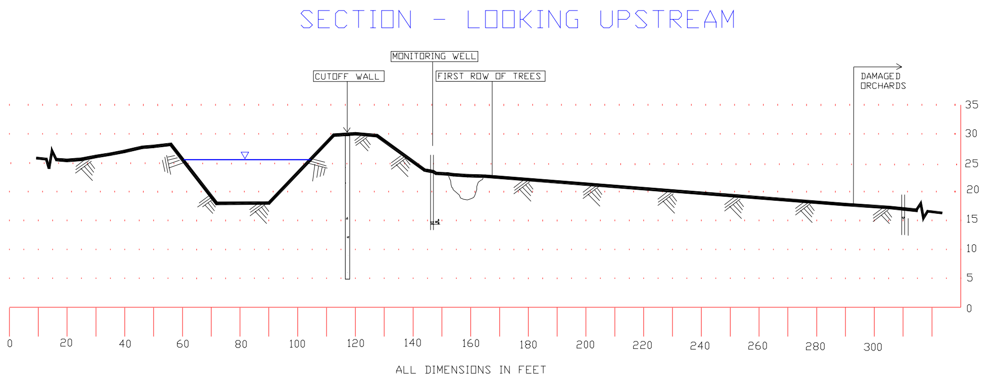
Various sizes of rubber were tested from crumb rubber to as large as 8 inch tire shreds.

After a design mix was established, a medium scale mix was constructed using a ready-mix concrete truck. From the results of this test, the mix was slightly modified and preparation for the large scale project commenced.

Large Scale Field Test

In May of 1999, a prequalification of contractors was conducted. Bid documents were prepared and bids were requested. In June of 1999, a construction contract in the amount of $243,000 was awarded to Inquip Construction. The project consisted of construction of 1,400 lineal feet of cutoff wall on a levee in Gridley, CA. The wall was constructed 30 feet deep.

The site selected is a DWR levee between the Sutter-Colusa canal and the Feather River. This location was selected because the canal adjacent to the levee is drained and filled annually thus providing a good opportunity for monitoring.



The cutoff wall took 30 days to complete. The project was constructed using two excavators, a track loader, and an integrated tool carrier. As the excavation progressed, the soil was placed in a 15 cubic yard (CY) mixing bin similar to a large garbage dumpster. Proper amounts of soil, cement, bentonite, and tire shreds were mixed and then placed at the opposite end of the excavation. As one excavator progressed with digging, the second excavator followed with the backfill so that the trench was not open more than approximately 100 feet at any given time. At the end of each shift, fence panels were placed over the excavation as a safety precaution to prevent someone from falling into the trench.

The contractor was required to follow USACOE specifications. Slump was measured on a regular basis. Custom cylinders were manufactured to conduct permeability tests. Compressive strength tests were conducted using 6” x 12” concrete test cylinders. All tests met specification.

The Recycled Tire Slurry Cutoff Wall Demonstration Project utilized 475 tons of tires. The tires were supplied to the project by the CIWMB at no charge to the project. Most of the tires used came from a legacy site in Oroville, CA. Procedurally, the contractor indicated that there was no additional cost or productivity loss due to incorporation of the tires into the backfill.

Monitoring of Results

After the project was constructed, nine-four inch diameter monitoring wells were installed. The monitoring wells provide an opportunity to measure the depth of the ground water to determine if water was migrating from the canal, through (or around) the cutoff wall.

Weekly groundwater measurements were taken over the course of two years. Preliminary results indicated that there was water moving from the canal to the adjacent land. In other words, when the canal was filled, the groundwater level on the opposite side of the wall increased as well.

In May, 2005, the canal was filled. Prior to filling the canal, water level logging equipment was installed. The water level logging equipment was programmed to take water levels in fifteen minute intervals. After evaluation of this data, it was determined that the water appears to be migrating through the levee at both ends of the cutoff wall (not through the wall). This finding concurs with the permeability laboratory tests. From all data available, it appears that the water is making an "end around" on the cutoff wall.

Laboratory Phase

Preliminary Investigations

Prior to commencement of laboratory testing, an informal literature review was conducted. Meetings were held with the USACOE engineering staff, and site visits were made to two different slurry cutoff walls construction sites. It became apparent that a Soil-Cement-Bentonite mix design was fairly well documented however there were significant obstacles when incorporating recycled tires into the mix.

Some of these obstacles included:

- Method of mixing materials in a large scale field test
- Method of testing permeability
- Method of testing slump
- Buoyancy of the tires
- Variations of soil classification used in lab tests from those actually found at the site

The results of these preliminary investigations concluded that there are various methods used to construct a slurry cutoff wall. The first project visited mixed the soil, cement, and bentonite using a dozer adjacent to the excavation. The mixing area was referred to as a “mixing bowl”. The second project utilized a large mixing box similar to a dumpster.

Another significant issue was the desire of CIWMB to maximize the use of tires. After significant discussions with the CIWMB, it was determined that crumb rubber was not preferred due to the cost of production. This presented a challenge regarding the testing methods which could be used.

Professor Dana Humphrey from the University of Maine who is a recognized expert in recycled tire projects was contacted. Dr. Humphrey had significant concerns about the potential for buoyancy. His concern was that the tires would “float” in the bentonite slurry as the backfill material was placed.

All of these concerns were significant and could not be ignored during the mix design process.

Mix Design and Parameters

Upon review of existing data and discussions with the experts in the field of slurry cutoff walls, initial mix design testing was conducted. More than 500 pounds of shredded tires were supplied to the CSU, Chico Research Foundation. The tires supplied were in various sizes ranging from 2” x 2” up to 8” x 8”. Test mixes were prepared in small electric drum mixer.

The tire shreds were subsequently relocated to the Concrete and Soils laboratory at CSU, Chico and preliminary tests were conducted. Preliminary tests were conducted using soil from the surface of the proposed construction site. By varying quantities of water, soil, bentonite, and cement, it became apparent that the 8” tire shreds were too large. Slump became difficult to measure and the 6” x 12” compressive strength molds did not readily accept the larger tire shreds. After significant efforts, it became apparent that 2” minus tire chips would provide the best workability and efficacy. At this time, 500 pounds of 2” minus tire shreds was delivered to CSU, Chico and an additional 500 pounds was delivered to the independent testing lab Vector Engineering.

Although the USACOE requires only eight hours for hydration of the bentonite, it was determined that twenty four hours assured full hydration and provided an effective slurry for testing. Mixes were tested using a three cubic foot electric concrete mixer. Each test mix was tested for slump and compressive strength. When a mix met both of these requirements it was sent to Vector Engineering for permeability testing. After approximately two months, a proposed mix design was achieved. Due to the viscosity of the mix, it appeared the separation of the tires from the slurry was unlikely thus alleviating most of the concern about the tires floating in the bentonite.

The final mix design proposed was:

Backfill Mix Design Provided to Contractors

Slurry Mix Item	Percent by Weight
Soil	67%
Bentonite Clay	3%
Cement	5%
Tire Chips	25%

Testing Procedures

Slump testing was conducted using the standard slump cone (ASTM C-143). The slump cone is considered accurate unless the maximum aggregate size exceeds 1.5 inches. For obvious reasons, the standard slump cone was not acceptable when using tire shreds. Even with smaller shreds, the tire chips tended to "stack" thus providing inaccurate results. To alleviate this concern, a Kelly Ball was utilized. The Kelly Ball utilizes a 6" diameter, 30 pound ball attached to a rod. A sample of slurry mix is prepared and struck off. The ball is then released and the depth of penetration is measured. The depth of measured can then be correlated to slump. The Kelley Ball test was formerly standardized in ASTM C-360-92.

Permeability Testing was conducted at Vector Engineering. Due to the size of the tire chips, special test cylinders had to be constructed. The cylinders were constructed of twelve inch diameter plastic pipe with a plywood bottom. The test procedure used was ASTM D-5084. It should be noted that the USACOE requires hydraulic conductivity not to exceed 5 x 10^{-7} cm/sec. This is the equivalent of 0.0000005 cm/sec. In some cases, the project achieved only 2.4 x 10^{-7} cm/sec. This difference is minimal and given the margin of error, it was determined to be acceptable.

Medium Scale Testing

In spring of 1999, a test was performed at Vector Engineering in Grass Valley, CA. This test involved mixing two separate batches of backfill material. With soil obtained from the site, there were two mixes prepared using a standard Cement mix transit truck.

The first mix used included the proposed mix design less the tires. The purpose of this test was to ensure that the matrix of soil-cement-bentonite would in fact meet the project objectives. The second test was the actual proposed mix design described above.

Both of these mixes were tested for both permeability as well as compressive strength. Although there were difficulties with the custom cylinders used for permeability testing, the mix was deemed adequate to proceed with construction of the large scale test project.

Full Scale Demonstration Project

Site Selection

Criteria for site selection included:

- Accessibility
- Acceptability to the landowner
- Indications of hydraulic conductivity
- Reasonable scale due to limited funding
- Location – Northern California

Numerous contacts were made with the water districts in the Northern California region including:

- Biggs-West Gridley Water District
- Butte Water District
- Levee District No. 1
- Plumas Mutual Water District
- Sutter Extension Water District
- Levee District No, 9
- Western Canal Water District

After numerous conversations with the water districts as well as various engineering firms, Mr. Paul Russell who is the manager and director of the Sutter Extension Water District confirmed that he had a potential site approximately 5 miles south of Gridley, California. He indicated that the levee had been documented with indications of hydraulic conductivity (seepage)

After visiting the site, it was preliminarily determined that this site had potential as a demonstration project. There was water in the adjacent canal. On the opposite side of the canal, there was a large "swamp" area with cattails, willows, and cottonwoods as well as an area of dead prune orchards.

The water district who owned the canal informed the CSU, Chico Research Foundation that the landowners of the orchards were the plaintiffs in the case of *Peekema Bros. v. Butte Water District and the Sutter Extension Water District, Butte County Superior Court Case No., 119687*. The Peekema suit alleged that water seepage from the canal through the levee was causing soil saturation in the orchard resulting in poor fruit yield and/or death to the orchard trees. The landowner (Peekema) had installed some monitoring wells along the canal and had documented the correlation between the water in the canal and the degree of saturation of the soil in the orchard. Indemnification (hold harmless) agreements were obtained from both parties in the litigation and site subsurface investigations were conducted.

In July, 1998, three soil borings were conducted on the crown of the levee. The soil borings were supervised by the independent testing lab, Vector Engineering and soil classifications were obtained using the Standard Penetration Test. Samples indicated that the levee was constructed of clay with thin layers of silt and sand. Based on the N-values of the Standard Penetration Tests, it was determined that a thirty foot deep wall should prevent any hydraulic conductivity between the canal and the adjacent orchard.

Permitting for the Project

Prior to commencing construction, all environmental and construction permits had to be addressed including:

- California Environmental Quality Act (CEQA)
- California Department of Water Resources (DWR) Reclamation Board Permit
- California Department of Fish and Game (DFG) 1600 Agreement
- US Army Corps of Engineers (USACOE) 404 Permit

Contractor Selection

It was determined that there were sufficient information in the plans and specifications to put the project out to bid as a lump sum fixed price contract. Prior to issuing bid documents, the CSU, Chico Research Foundation project team issued a Contractor Prequalification form to ensure that only qualified bidders would submit a price for the project.

The process revealed two contractors who were experienced in Slurry Cutoff Walls in the region. Inquip Construction, and Geo-Con Construction. Fixed price bids were received and Inquip was the lowest responsive, responsible bidder.

A fixed price contract for $243,000 was awarded to Inquip Construction.

Construction Process

The contractor mobilized the project on June 12, 1999. The process of setting up temporary power, bentonite mixing tanks, and the HDPE slurry supply pipe took approximately five working days. Excavation of the cutoff wall commenced on June 17, 1999. The equipment utilized included:

- 2 Caterpillar excavators – One at each end of the trench. The lead excavator was digging the trench and the second excavator was mixing and placing the Soil-Cement-Bentonite-Tire mix for backfill.
- 1 Caterpillar Integrated Tool Carrier (ITC) – This piece of equipment served many purposes. With it interchangeable components, it can serve as a forklift to offload cement and bentonite from the delivery trucks. The ITC can also attach a front end bucket to serve as a loader, and a boom which allowed carrying heavy loads. The primary function of the ITC was to deliver cement to the mixing bin.
- 1 Caterpillar 953 Track Loader – The track loader is similar to a rubber tired front end loader only it is mounted on tracks for traction and flotation. The track

loader was used to load soil and tire chips into the mixing bin. Once all materials were measured and placed into the mixing bin, the front end loader would agitate the materials to mix them prior to placement.

- 1 – 6” contractors pump – the pump was used to supply water to the bentonite hydration and mixing tanks. The water was supplied from the canal which is fed from the Feather River.

QA/QC

The process of QA/QC was dictated by the USACOE specifications. All requirements were followed and documented. Slump, Permeability, and Compressive Strength were all measured as required by specification. As an observation, it should be noted that compressive strength testing was very unique due to the tire content. Unlike concrete, the samples failed at a low compressive strength however their volume typically rebounded due to the plastic behavior of the tires.

Lessons Learned

While the project outcome is considered successful, there are a few items which could be improved upon should this process be replicated. The following are a few suggestions which could improve the process of utilizing recycled tires in a slurry cutoff wall.

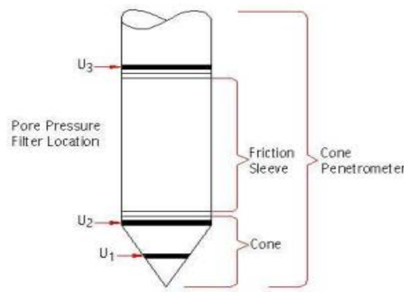
1. Tire delivery and mixing – On this project, the tires were delivered using a typical lumber chip truck with a moving conveyor floor. The trucks arrived at the site, opened up the rear doors, and the chips were dumped into a pile near the worksite. The track mounted loader (Caterpillar 963) then measured the proper number of bucket loads and moved them into the mixing bin. Upon completion of the project, there were significant numbers of tire chips in and around the site

which were required by the Department of Water Resources Inspector to be cleaned up. The recommendation would be to have the tires measured at the chipping facility and placed in bags or bins for placement into the mixing bin.

2. Backfill – It is suggested that the trench, not be backfilled to the upper limit. If the trench is backfilled to the top and the road is reconstructed, there are tire chips sticking out of the finished cutoff wall. It is suggested that the backfill be held to approximately one foot below the crown of the finished roadway. Clay soil could then be used in the top one foot of the wall with aggregate base on the finished surface.

Monitoring

Post Project Preliminary Monitoring



Upon completion of the project, and during reconstruction of the levee road, a Caterpillar 613 scraper encountered "soft" soil at the very north end of the project near the apron at Chandon weir. The scraper sunk into the soil to a depth of approximately three feet. This caused significant concern to the Department of Water Resources. At this time, a Cone Penetrometer test was performed on the cutoff wall. The Cone Pentrometer test is a method of probing vertically into a soil medium and measuring the tip resistance. Given a large enough sample, this test would indicate if any voids exist in the cutoff wall. Simply stated, if there was a void in the cutoff wall, the tip resistance would be significantly reduced. No such drop in resistance was found. Conversely, a significant problem with the apron at the Campbell weir was found. There were large voids behind the apron and it became apparent that water has scoured the soil behind the apron. This coincides with the data indicating that water appears to migrating through the levee at the north end of the project (monitoring well number 1) faster than at any other location.

Methods of Periodic Monitoring

Upon completion of construction, nine monitoring wells were installed at the site. Eight of wells were equidistant at the toe of the levee (parallel to the cutoff wall) and one additional well was installed in the middle of the existing swamp. Water level measurements were taken weekly using a water level sounder. The water level sounder is a device in which a probe is dropped into the well. The probe is attached to a flexible wire which has a tape measure engraved. When the probe encounters the water surface an audible sound is heard and the depth can be measured from the top of the well.

Using a known benchmark, the tops of the wells were then converted into real elevations using common surveying methods. A Topcon GTS-310 Total Station was utilized. The known elevation is DWR benchmark FR-47 located on

Chandon Weir which is approximately 1,000 feet downstream from the project. The elevation of FR-47 is 91.395 USACOE 1991 datum.

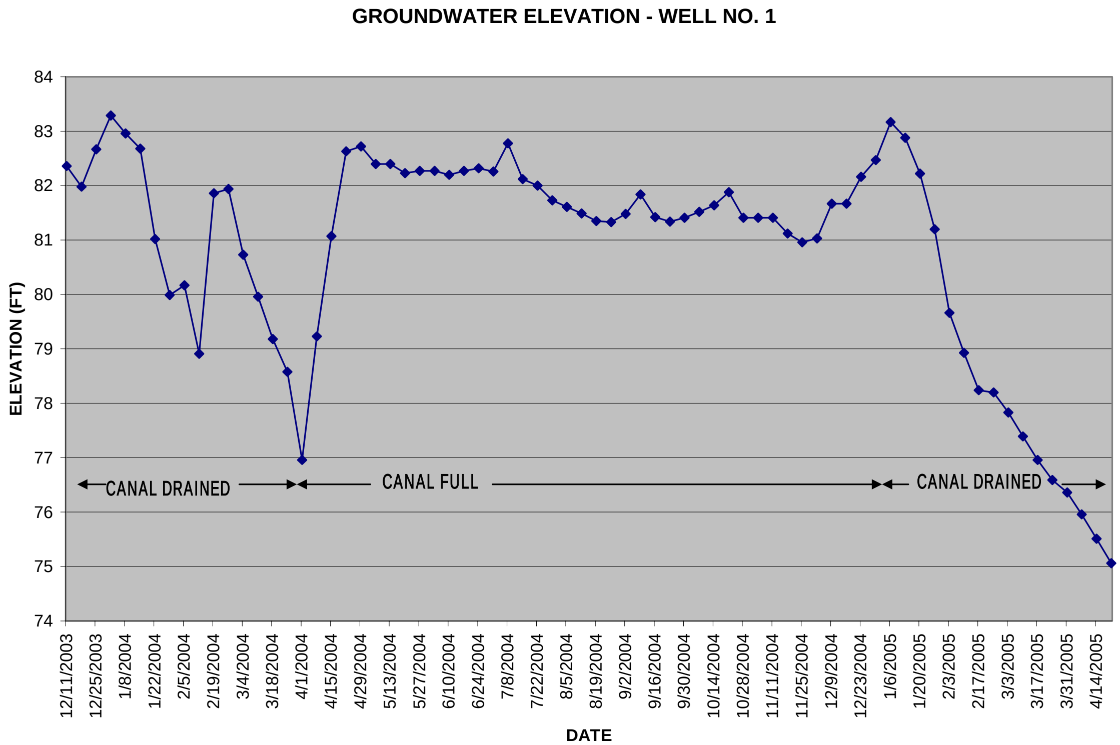
Using this data and the topographic survey conducted, the tops of the wells were found to have the following elevations:

Well Elevation Data

Well Number	Elevation (ft)
1	89.16
2	89.36
3	89.30
4	88.72
5	87.78
6	89.50
7	90.96
8	92.08
9	82.10

Results of Periodic Monitoring

After two years of weekly readings, it was readily determined that there is a correlation between the draining of the canal and the groundwater level on the opposite side of the cutoff wall. Similarly, the filling of the canal showed an increase in the groundwater. A sample graph is shown below. The remaining graphs are included in Appendix C. The data proved similar for all of the wells. In short, when the canal is filled, the groundwater rises in the adjacent property. Similarly when the canal is drained, the groundwater lowers. What was unclear is whether the water was going around, under, or through the cutoff wall.

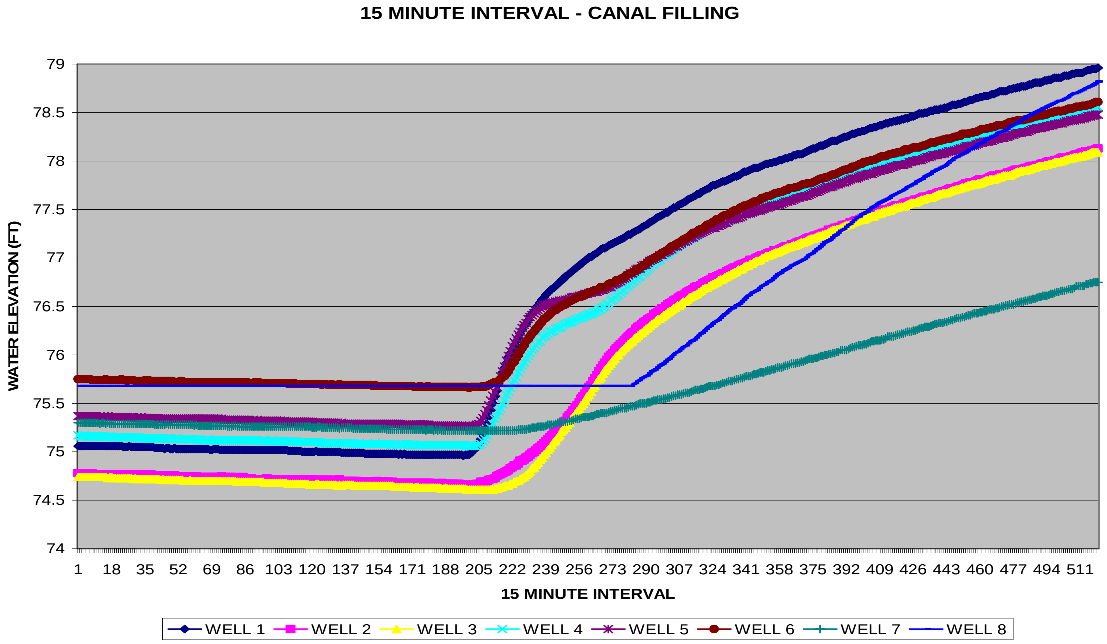


Secondary Monitoring Method

To answer the question of how the water was migrating from the canal to the adjacent field, a water level data logger was installed in each well prior to the canal being filled in April, 2005. The logger used was a WL-15X Water Level Logger produced and distributed by Global Water Instrumentation, Inc. The water level data logger is a device installed into the well and programmed to take elevation readings at a given time interval. For this project, the data loggers were programmed to take elevation readings every 15 minutes for a two week period. The loggers were installed on Friday, April 22, 2005 and retrieved on Friday, May 6, 2005. The Joint Board Water District began filling the canal on Monday, April 25, 2005.

Results of Secondary Monitoring Method

On May 6, 2005, two weeks of "real time" monitoring data was downloaded from the data loggers. The water levels in the wells increased when the canal was filled. The question was not whether the water levels would rise but more importantly would they increase equally (indicating a cutoff wall failure) or would the water level rise at each end (or one end) indicating that the water was making an "end around" on the cutoff wall. It is important to note that the Joint Water Board has had significant problems with the levee and is currently making repairs in other locations. There was suspicion on the part of the CSU, Chico Research Foundation representatives that the water was coming through the levee at the north end of the project. The north end of the project is adjacent to the Campbell Weir. Just downstream of the weir is a concrete apron that appears to be eroded. There are visible signs of voids behind the apron which were caused by scour from the water moving through the weir and the associated eddy currents. The following chart is an indication of how the water level changed during the first week after the canal was filled. Additional charts are provided in Appendix C.



Summary

Five years has elapsed since the completion of the Recycled Tire Levee Slurry Cutoff Wall Demonstration project. While the cutoff wall has met the laboratory specifications there are still many questions including:

- Is the cutoff wall functioning?
- Is the cutoff wall deep enough?
- Is the water migrating around the ends of 1400 lineal feet cutoff wall?
- Is the recycled tire integration feasible from a cost perspective?

With respect to the wall function, the data is promising. There is sufficient data to opine that the water is migrating around or under the cutoff wall (see appendix C). The cutoff wall construction process was not affected by the incorporation of recycled tires. The concerns of tire flotation were not encountered in the construction process due to the viscosity of the backfill material and solifidification over time.

While analyzing the cost is difficult, it is recognized that the project used approximately 475 tons of tires. Assuming that these tires could be produced at a cost of $20-$25 per ton and that trucking to the north state would cost approximately $300 per truckload, the increased cost of construction to this levee project would be approximately $20,000. While this cost may seem significant the unit cost of this is very insignificant.

At the time of construction of the Levee Slurry Cutoff Wall Demonstration Project, the USACOE was experiencing a typical cost of $6.00 per square feet. Since this project was 1400 lineal feet long and 28 feet deep, this equates to 39,200 square feet. Assuming that a similar project could be constructed, the increased cost of incorporating recycled tires would be:

$$\frac{\$20{,}000}{39{,}200\,lf} = \$0.51\ \textit{per square foot or an increase of}\ 8.5\%\ (\textit{as compared to}\ \$6\ \textit{per lf})$$

Conversely, if 25 miles of cutoff wall was constructed each year and the average depth was 40 feet, this would equate to 5,280,000 square feet of cutoff wall constructed. Using the average tire usage from the Recycled Tire Levee Cutoff Slurry Wall Demonstration Project, it is reasonable to consider that 63,980 tons of tires per year could be disposed. 63,980 tons of tires equates to approximately 6.4 million tires per year.

Abbreviations and Acronyms

CIWMB: California Integrated Waste Management Board

DWR: California Department of Water Resources

DFG: California Department of Fish and Game

F_c: 28 Day compressive strength

S-C-B: Soil-Cement-Bentonite Slurry Cutoff Wall

S-C-B-T: Soil-Cement-Bentonite-Tires Slurry Cutoff Wall

USACOE: United States Army Corps of Engineers